Military Air Systems

Structural Design Aspects and Criteria for Military UAV

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Introduction

- Structural design criteria have been developed over decades for manned air vehicles, serving a variety of missions, service requirements and environmental conditions. These criteria used have been evolved and advanced for large fleets of manned platforms using the experience from ground and flight tests and thousands of mission flight hours for different usage scenarios.
- Acceptable structural safety levels required for peacetime operations and mission performance in war times have been ensured through extensive qualification processes and specified military certification requirements.
- New systems like unmanned air vehicles are now in various stages of conceptual design, development or production. These unmanned systems may use either variations of the design criteria for manned air vehicles to fulfil similar requirements where applicable and new design criteria where specific unique weapons system capabilities are demanded, along with certification guidelines being formulated by authorities to operate the vehicle in various classes of airspaces.

continued

Introduction (continued)

- Beside accelerated development and entry into service schedules one important element in UAV’s platform design are the cost aspects both in terms of acquisition and in-service usage. Projected cost advantages of UAV’s can be compromised if "traditional" design criteria and certification requirements are imposed upon them, leading to production costs increase or delays in acquisition and vice versa. Relaxation of qualification levels without adequate technical substantiation followed by unacceptable failure rates in service will also compromise system cost advantages over manned vehicles.
- The intent of this paper is to present some UAV design aspects and structural design criteria based on current projects and in view of initial proposals for European UAV regulations (e.g. CS23 / USAR) emphasizing the importance of UAV specific Structural Design Criteria, i.e. definition of limit / ultimate load conditions (factor of safety – no pilot in the loop), structural safety provisions for UAV’s, aspects of flight envelope definition (e.g. FCS controlled / “protected” envelope, etc.).
- Also possible future design drivers with pilot based restrictions removed for high agile manoeuvring for UCAV's are considered together with new aspects like transport requirements (sea, road, air). Future challenges for the UAV structural clearance process, i.e. qualification / certification standards and demonstration

Current Qualification/Certification

Typical Requirements / Guidelines:

- **Structures General:**
  - MIL-Spec. A-886x and A-83444-Series
  - CS 23 and CS 25 (tailored)
  - LTF 1550-001, Issue 1
  - USAR 3.0
- **Composites:**
  - FAA AC 20-107A “Composite Aircraft Structure“ (FAA Advisory Circular)
  - MIL- HDBK 17 (only composites – military / civil)
  - BWB-ML 84-149:
  - Anforderungen und Nachweisführung für Luftfahrtstrukturen aus CFK (German guidelines – comparable to FAA AC…)
- Most requirements are adapted from manned aircraft to **specific** project based needs, not a “set of evolutionary improved, usage related requirements of an UAV”

Unmanned Military Air System Classes (1)

MALE – Medium **A**ltitude **L**ong **E**ndurance Air Vehicle
HALE – High **A**ltitude **L**ong **E**ndurance Air Vehicle

- low speed ⇨ sailplane respective transport aircraft attributes
- mission altitude ⇨ max. altitude > 40000 ft
- long endurance time ⇨ ≥ 20 h
- low manoeuvre load factors (g), low roll velocity
- structural design is driven by gust conditions
- geometrical design ⇨ driven by mission payload requirements mainly ?
- fatigue requirements ⇨ high sortie rate per year
  life time ≥ 20 years

Unmanned Military Air System Classes (2)

URAV – Unmanned **R**econnaissance **A**ir **V**ehicle

- low altitude missions ⇨ $\geq$ 1000 ft
- subsonic flight envelope
- more agile air system ⇨ increase of g and roll velocity compared to MALE, HALE
- structural design: driven by manoeuvre loads
- geometrical design: driven by mission payload requirements mainly
- fatigue requirements ⇨ low sortie rate per year
  life time $\geq$ 20 years
- first combat capability ⇨ external stores and/or internal weapon bay
  ⇨ small weapons only (no missiles ?)
- stealth requirements ⇨ RCS, IR ?

Unmanned Military Air System Classes (3)

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UCAV – Unmanned Combat Air Vehicle

- Design for
  - subsonic / transsonic / supersonic flight envelope
  - multifunctional structures*, morphing structure
- Agile air vehicle
  - **equivalent** to manned fighter aircraft: air to air and/or air to surface role
  - **or** even higher agility required: nz, roll velocity etc
  - geometrical design is driven by mission performance
- High combat capability ⇨ external weapons and/or internal weapon bay
- Fatigue requirements
  - very low sortie rate per year
  - or use of UCAVs in war times only:
    fatigue loads are occuring in the short period during war time missions
    special storage requirements
- Stealth requirements ⇨ RCS, IR ?

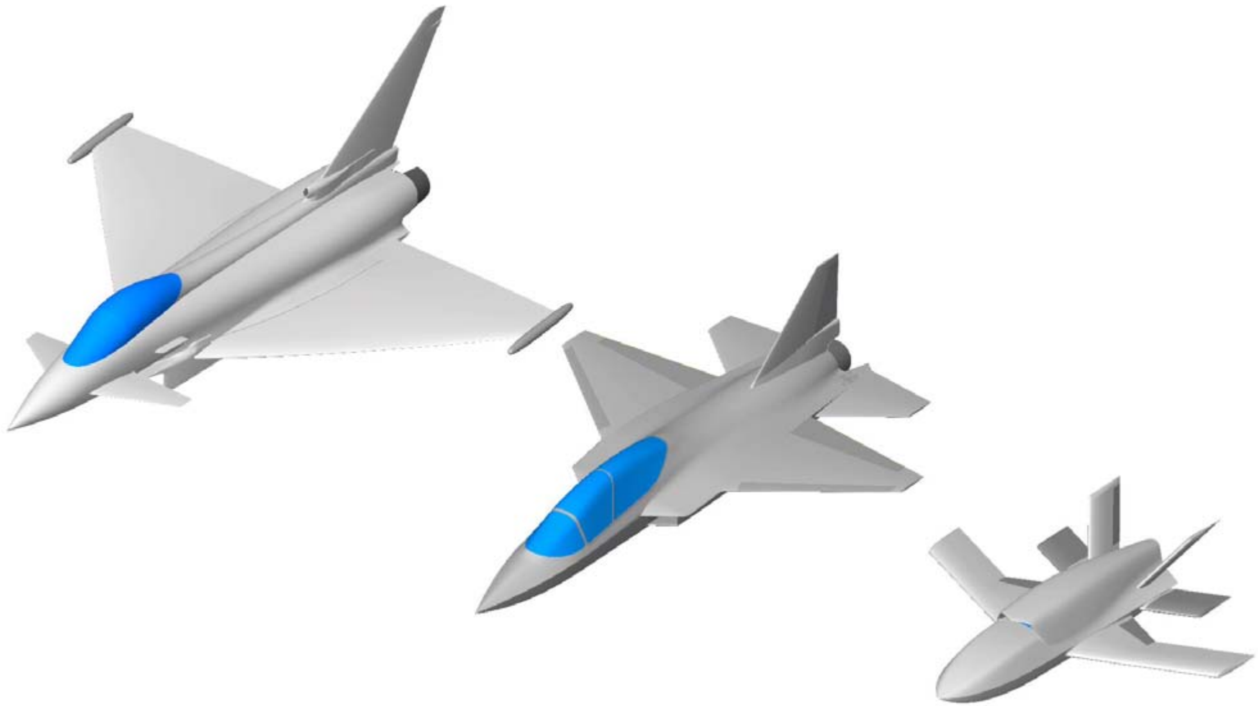
* see also Design Aspects from AVT141: integration of Sensors and Antenna

General Design Requirements

Design for UAVs essentially follows the same rules as for manned Air Systems, but

- requirements may be narrowed down or relaxed because
  - no safety requirements for a crew or passengers
  - specialized usage
  - possibly restricted flight areas
  - small fleets of A/C
  - orientation to all composite structures (⇨ fatigue, corrosion)
  - autonomous flight control systems
- requirements might be more demanding because there is no pilot intelligence
  - bird strike, icing, lightning
  - CAT 2 & 3 certification, i.e. flying over populated area / participation in civil airspace

Comparison between manned Aircraft and UAV



If UAV structures are compared to structures of manned A/C, first of all the weight class of the vehicles and their flight envelope should be similar.

Spiral Development as a New Design Concept

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- „Spiral development“: development is possible even if the requirements for certain future capabilities cannot be formulated at the time being
- Leads to a more rapid procedure to put air vehicles into service and profits by future technological developments
- Constantly developing avionic equipment and varying requirements for missions make UAVs a favourable candidate for spiral development
- Issue: How will „spiral development“ influence design requirements?

Requirement Capturing

The customers should rethink their requirements:

- to really make UAVs cheaper it is important not to overload the specifications.
- instead a detailed feeling for **cost against performance** has to be established between manufacturer and customer.

Spiral developments cycles will provide faster time to operational service with less than spec-optimums, but steeper “learning curve” with close link between field experience and design upgrades.

It can be observed that a role change or at least adaptation (common in manned combat aircraft) takes also place in mid and large size UAVs. UAVs designed as pure reconnais-sance platforms are adapted to carry weapons, while UCAV designs are adapted to reconnaissance missions.

Design Requirements and Qualification for UAV

Traditional Task:

Convert the users need (purchase and operational) i.e. fleet size, operational performance, safety aspects, certification, cost per unit, maintenance concepts, life cycle cost etc into structural design requirements

Modified Task for UAVs:

Ensure the process of development and certification is kept safe (comparable to manned aircraft) at the systems level, but at the same time accelerated and simplified to support new project requirements (i.e. spiral development)

Special Conditions

- Bird strike:

  be sure that bird strike does not damage integrity of structure (e.g. wing tanks) or impair functionality (equipment)

- Lightning strike:

  protect structure and equipment against lightning strike:

  ⇨ copper foil or copper mesh, electrical bonding

- Icing:

  icing spoils aerodynamic characteristics and may lead to loss of air vehicle:

  ⇨ de-icing capability will be required in many world region
  ⇨ fluid or electrical de-icing

SDC: Differences manned/unmanned air vehicles

Crash conditions

Manned fighter aircraft are designed to crash conditions (attachments of ejection seat, cockpit environment, fuselage tank bulkhead etc.)

Not applicable to UAVs because no pilot has to be protected

Protected envelope

The Flight Control System (FCS) has to control unmanned air systems to reach a comparable level of safety as for manned air systems – flying over populated areas

Transport by land, air and sea

Normally not necessary for manned air systems but unmanned systems (up to intermediate sized) will be transported close to the operation area

Use of UCAV primarily in war times

Long-term storage necessary: storage time and storage requirements (maintenance) to be defined

Modularity

UAVs operational requirements may change fast.

Hence modularity is always a major design aspect.

- Modular payloads for easy change from one mission to the other
- Replacement of an internal weapon bay for a payload bay
- Modularity with respect to solve the obsolescence problem (electronics, sensors)
- Modularity may also be a means to change airframe performance characteristics
- Modularity of structural components as prerequisite for easy transportation

Design Aspects from AVT141 - Integration of Sensors and Antennas

- **Possible next generation integration aspects:**
  - conformal load bearing antennas
  - radomes included in load carrying structures
  - shape/vibration control of antennas (beam steering, sidelobe level)
  - thermal management problems from embedded electronic subsystems, including thermo-electric-energy harvesting systems
  - structural/system health sensing systems:
    sense ⇨ diagnose ⇨ respond

- **Possible consequences:**
  - integration of two “manufacturing worlds” into one on vehicle systems level: structural production shop environment & sensor clean room requirements?
  - new production processes and qualification concepts on systems level required for sensors & structures?
  - combined qualification test concept for sensors & structures required

Factor of Safety (FoS) – Re-Evaluation for UAVs

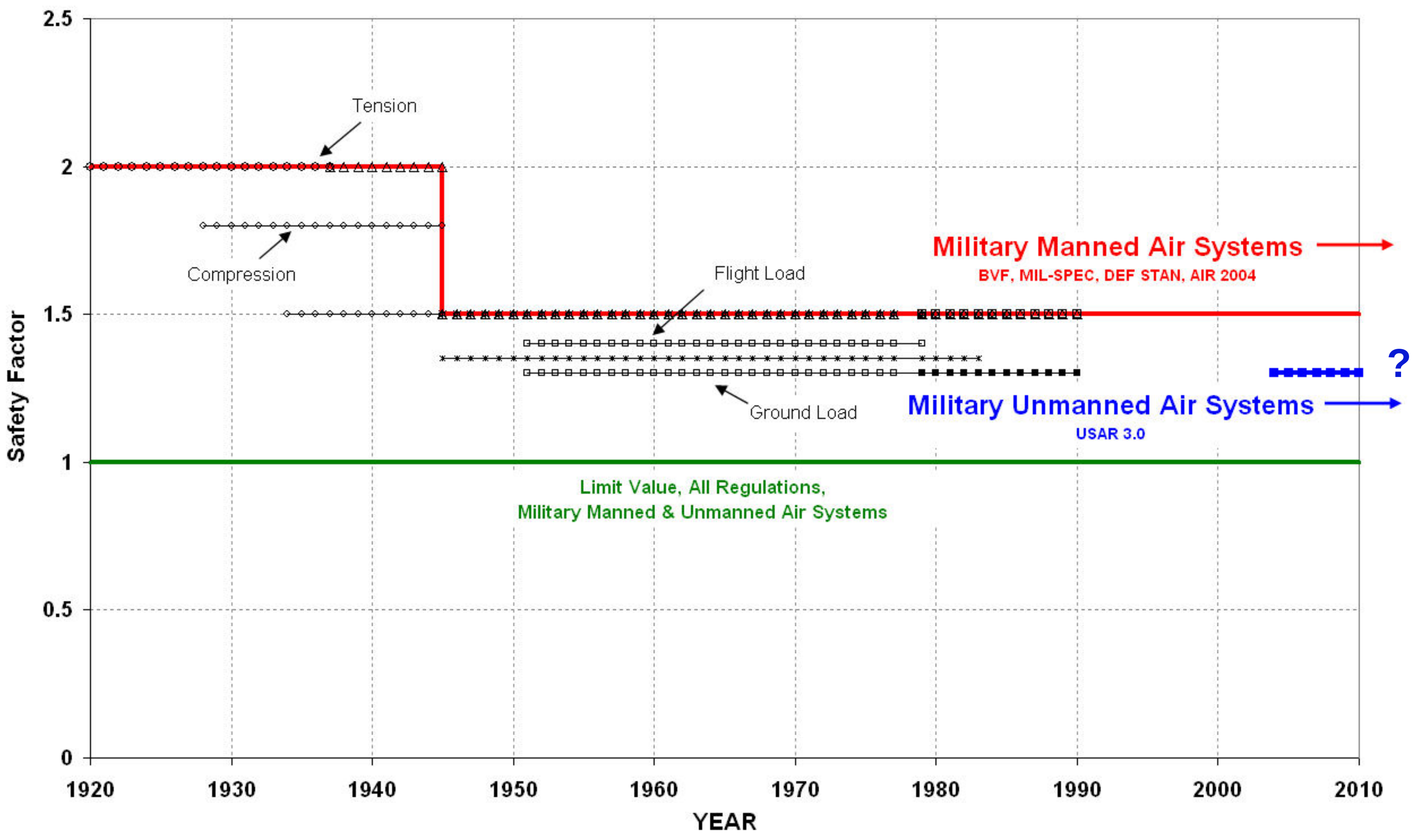
- The FoS is under discussion since technical pretentious manned air systems are in the air. Cost saving, i.e. mass reduction is the main driver to reduce the FoS.

  The possibilities for FoS reduction are based on better design tools, more accurate load calculation, effective flight control systems (e.g. FCS as a load limiting system) and extensive structural health / event monitoring.

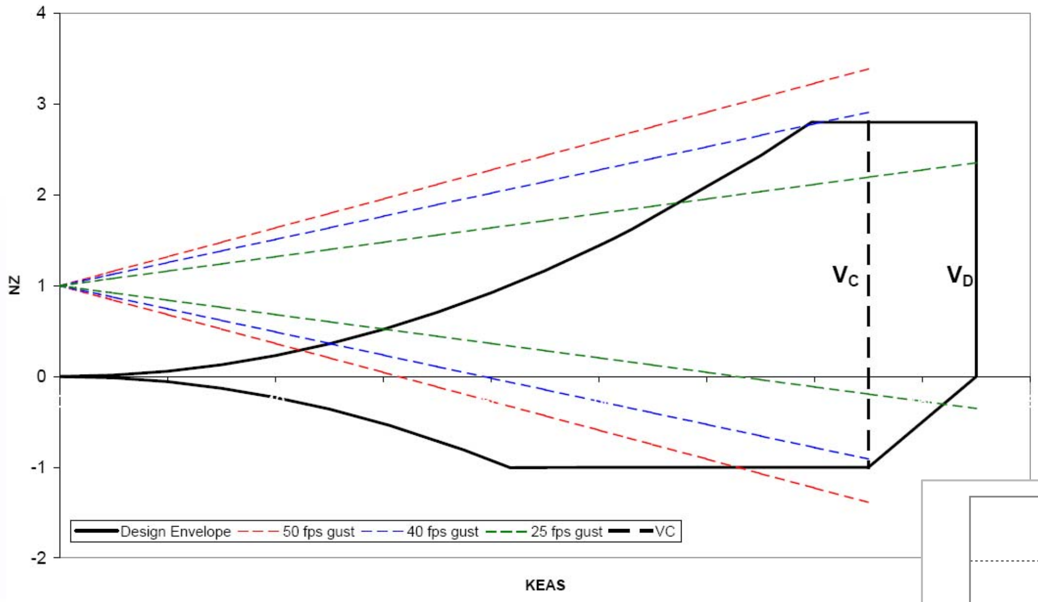
  For **unmanned air systems** the simple but crucial argument is that **no pilot** has to be protected - but probably pilot skill will be missing when **flying over populated areas.**
- Today the military regulations (e.g. Mil. Spec., Air 2004, Def. Stan.) and civil regulations (e.g. CS23, CS25) for manned air systems are generally requiring a FoS of **1.5** with some deviations
- the USAR 3.0 (derivation from the civil regulation CS23) a first european (french) regulation for unmanned air systems basically requires a FoS of **1.3*** with some additional safety factors (e.g. fitting factors) for critical design areas (e.g. wing attachments)
- amount of conservatism: reduced, how?

*recent USAR Versions are requiring also a FoS of 1.5

History of the Factor of Safety



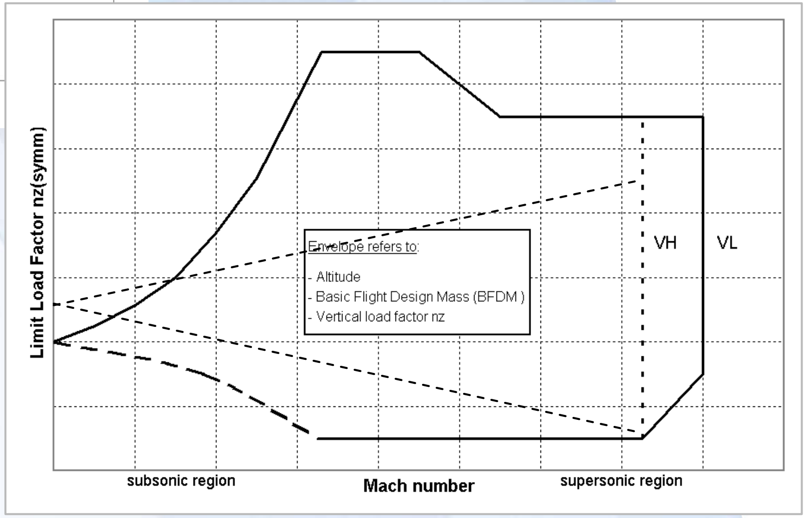
Comparison of Design Envelopes (V-n diagram)



Typical MALE / HALE Envelope:

- low speed envelope
- low g- manoeuvres

Structural design mainly driven by gust loads



Typical manned Fighter Aircraft Envelope:

- supersonic envelope
- high g- manoeuvres

structural design mainly driven by manoeuvre loads

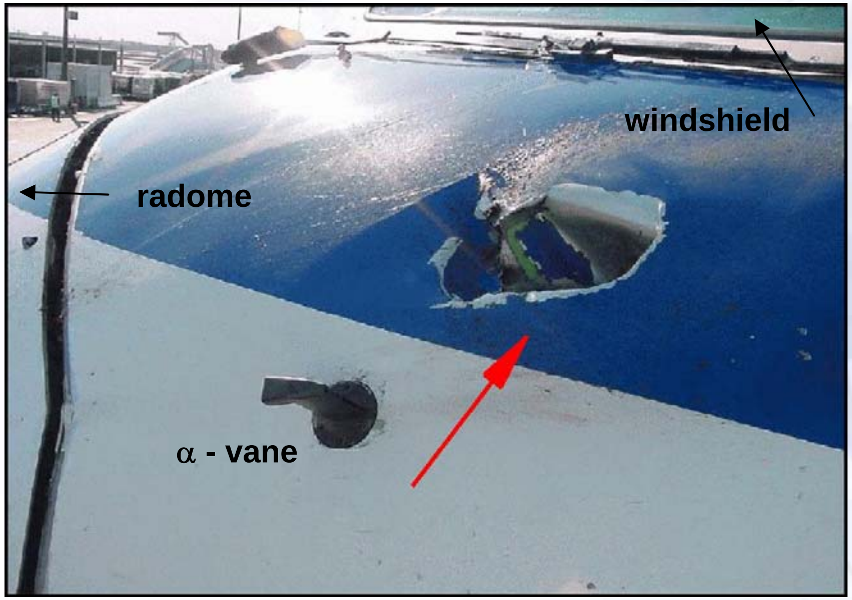
UCAVs:
Is there a requirement for higher agility (nz >9, roll rate, etc)?

Structural Health (SHM) and Event Monitoring

Health & event monitoring (real time) could be more important than in manned air systems, i.e. extension of health & event monitoring to areas usually observed by the pilot may be necessary (pilot also working as a “sensor system” in manned air systems):

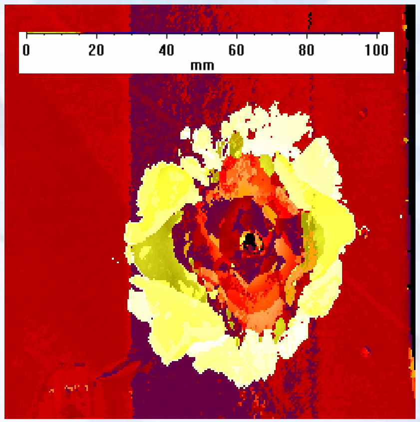
- bird strike
- lightning strike
- monitoring of general vibrations, acoustic noise (high cycle fatigue)
- dynamic loads ⇨ e.g. monitoring of local accelerations from gust, buffet, dynamic landing impact
- pilot observed aging effects (wear and tear) ⇨ change of maintenance concept, e.g. additional inspections may be necessary

SHM: Examples for Event Monitoring



Bird strike below windshield of a civil Airliner

for UAV's decision from ground station necessary: return to base or continue with flight



Foreign object impact damage to monolithic carbon fibre composite:

- bird strike
- hale
- runway stones
- etc.

significant damage can be shown after flight by ultrasonicC-Scan of damaged area

Design aspects: Transportability / Maintainability

Transportability is also a key to UAV operations. The intermediate size UAVs will be transported close to the operation area.

Therefore it must be possible to quickly assemble and disassemble the A/C with simple means available on forward bases. Mostly the size limitations of transport A/C are the limiting factor.

These transports may in some cases add design load cases to the load envelopes for structure and system layout.

Not only influences of the transport on the vehicle have to be taken into account, but also implications of the UAV for the transport vehicle. This may lead to sealing of tanks to prevent vapour leakage into the transport A/C cabin, other containment, or pyrotechnic issues.

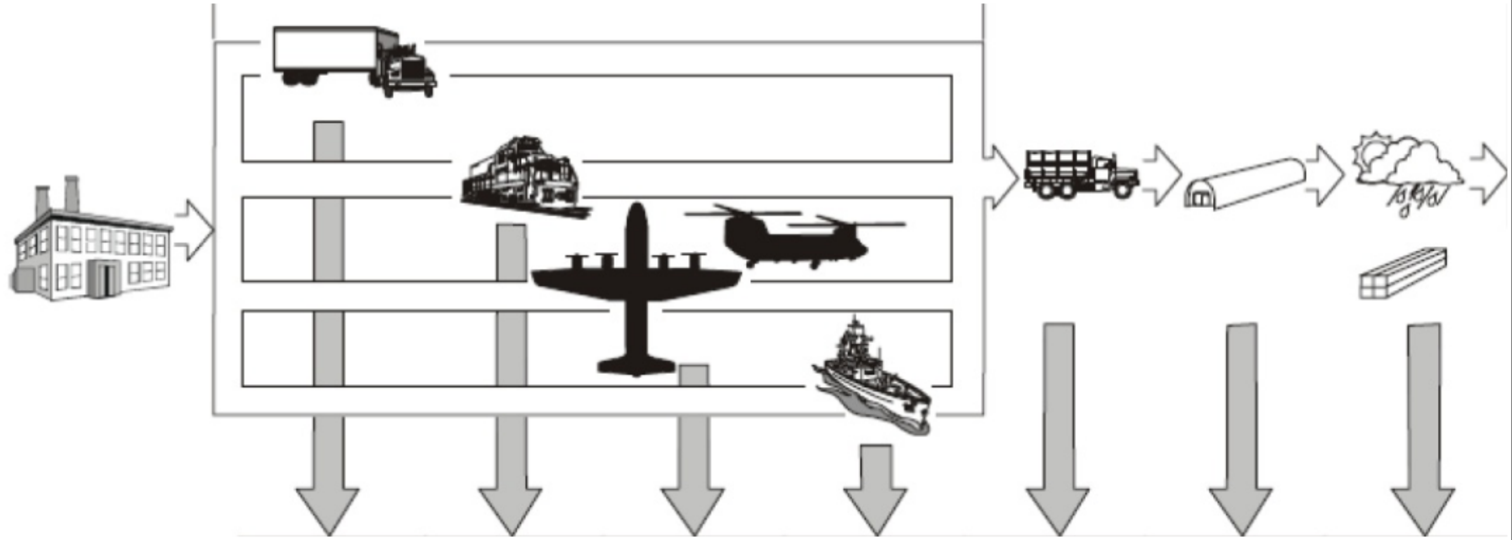
Transport conditions

Consideration of different transport conditions by air, land and sea: the table shows a summary of typical (limit) load factors which might be applicable for design

Medium/mode	Longitudinal load factors, g	Lateral load factors g	Vertical load factors g
Water	± 0.5	± 2.5	+ 2.5
Air	± 3.0	± 1.5	± 3.0
Ground			
Truck	± 3.5	± 2.0	+ 6.0
Rail (bumping shocks)	± 6.0 to ± **30.0**	± 2.0 to ± 5.0	+ 4.0 to +**15.0**
Rail (rolling)	± 0.25 to ± 3.0	± 0.25 to ± 0.75	+ 0.2 to + 3.0
Slow-moving dolly	± 1.0	± 0.75	+ 2.0

(table from NASA SP-8077)

Transport: Adaptation to Mil-STD-810 requirements for equipment



	Handling & Road Transportation	Handling & Rail Transportation	Handling & Air Transport	Handling & Ship Transport	Handling & Logistics Transport (Worst Route)	Storage, Sheltered (Tent, Shed, Igloo)	Storade, Open
	Road Shock (Large Bumps / Potholes) Road Vibration (Random) Handling Shock (Dropping / Overturning)	Roll Shock (Humping) Roll Vibration Handling Shock	In-Flight Vibration (Engine induced) Landing Shock Handling Shock	Wave induced vibration (sinusoidal) Wave Sine Shock Mine/Blast Shock Handling Shock	Road Shock (Large Bumps, Holes) Road Vibration (Random) Handling Shock, Thermal Shock	None	None
	High Temperature (Dry / Humid), Low Temperature Rain/Hail Sand/Dust	High Temperature (Dry / Humid), Low Temperature Rain/Hail Sand/Dust	Reduced Pressure Thermal Shock (Air Drop only)	High Temperature (Humid), Low Temperature, Rain Temporary Immersion Salt Fog	High Temperature (Dry/Humid), Low Temperature / Freezing, Rain/Hail Sand/Dust, Salt Fog Solar Radiation Reduced Pressure	High Temperature (Dry/Humid), Low Temperature / Freezing, Salt Fog Fungus Growth Chemical Attack	High Temperature (Dry/Humid), Low Temperature / Freezing, Rain/Hail Sand/Dust, Salt Fog Solar Radiation Fungus Growth Chemical Attack

Reqirements for Transport and Maintenance

- Usage of standard containers (e.g. 40 ft container)
- Clear hoisting and jacking concept, also covering emergency conditions during transport (damping etc)
- Convenient mission payload maintenance (special compartment and / or container)
- Easy access to panels, bays, systems interfaces – is sometimes difficult because of limited space

Storage

Structures are normally not affected by storage under controlled environmental conditions, but systems especially those with liquids are prone to damage during long storage.

Here is one of the real benefits of “more electric A/C”.

Production Numbers, Cost & Repairability

The limited production numbers of UAVs and their (comparatively) low price implies that no major qualification processes can be performed.

Therefore dual use materials or materials qualified in other projects will be the materials of choice.

Hence the cost share of the airframe for the single A/C is expected to be considerably lower than for a manned A/C, the money is spent primarily for sensors and electronics and not for the structure itself.

Likewise repair ability has to be handled different compared to manned A/C: it should be possible to exchange components and perform minor repairs on deployment bases, without major facilities: rapid simplified repair concepts

Qualification / Certification - Overview

Today most UAV certification rules and procedures adopt civil regulation documents and processes like JAR/CS 23 & 25, depending on the maximum takeoff weight and aeroplane category, often tailored to serve one specific product.

With the traditional certification rules, evolutionary improved, based on decades of service experience in civil operations, new, global standards are needed for UAVs. They must include UAV- specific features like FCS protected loads- and flight envelopes to assure a comparable level of safety as manned aircraft in peacetime operations.

Goal:

“Assure Structural Integrity (i.e. Static Strength, Durability, Damage Tolerance) of a vehicle structure throughout its specified usage without imposing an unacceptable threat to safety or economic burden through failure of structural components to the customer”

Task:

Demonstration of the structural integrity to the customer through an agreed validation and acceptance program for all structural significant items.

Structural Qualification Process for UAV's

Definition of a new Structural Qualification Process for UAVs seems to be necessary:

- reduced / limited number of Production Aircrafts
- spiral development process
- shorter and overlapping development cycles: e.g. concept definition ⇨ production
- very low sortie rate per year for UCAV respective use of UCAV in war times only
- use of FCS as "load limiting system" ⇨ reduction of FoS for FCS controlled flight loads
- last but not least ⇨ no pilot has to be protected

Consequence:

Investigate the potential to reduce the amount of structural/system qualification tests:

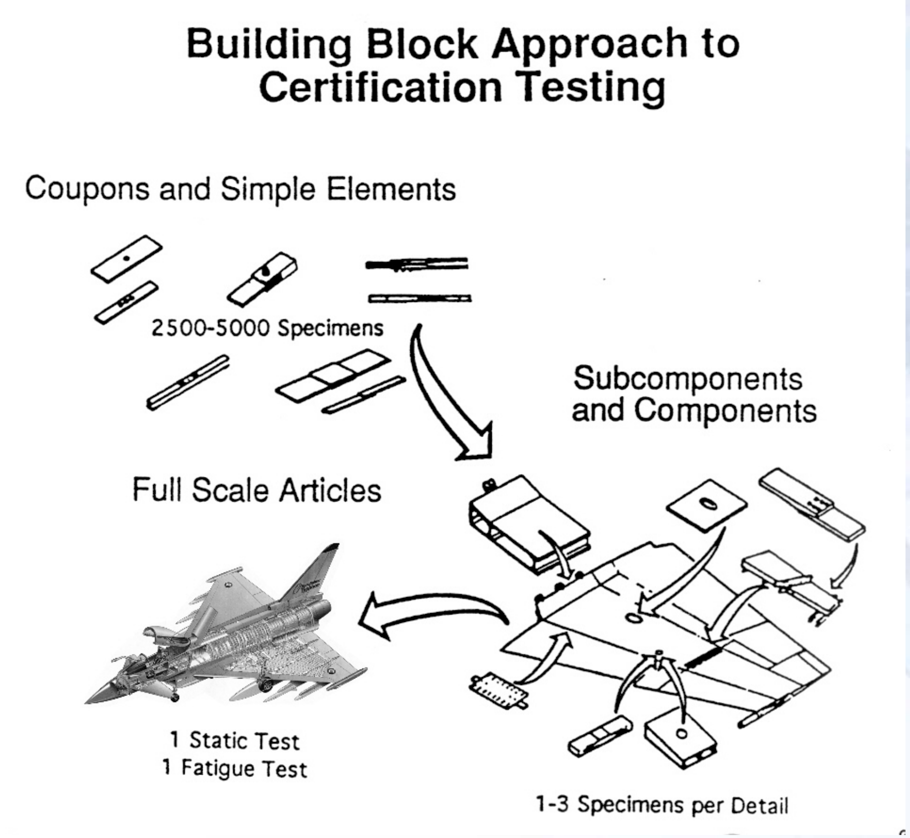
Example: Structural qualification test steps transferred from ground to flight test

- up to limit loads ⇨ flight test with improved real time flight loads instrumentation
- up to ultimate conditions ⇨ qualification by analysis (see also AVT 092)

But:

A comparable level of safety as for manned air systems is required:
⇨ flying over populated areas (CAT 2 / 3)

Qualification/Certification Testing



New approach*:

Coupons:
dual use or read across?

Elements:
read across or more testing?

Subcomponents / Components:
less testing?

Full Scale:
no tests?

*see also qualification by Analysis: **AVT 092**

Qualification / Certification Process for UAV's

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Definitions according to LTF 1550-001, Issue 1*

CAT 1: flying in restricted areas only → test areas without population:

- ⇨ experimental UAV's / prototypes
- ⇨ flight test activities

structural qualification by analysis only:

- ⇨ structural qualification tests are not necessary except GRT (SCT)
- ⇨ but flight test results can be used for structural qualification possibly

authorities not really involved in UAV clearance process:

- ⇨ provide evidence to the authorities only that the UAV cannot leave the restricted area (e.g. flight abortion system)

CAT 2: flying in restricted airspace over populated areas:

- ⇨ "full" structural qualification / certification process necessary ?
- ⇨ provide evidence to the mil. / civil authorities that the UAV can fly safely
- ⇨ comparable level of safety as for manned air systems

CAT 3: participation in civil airspace without restrictions (sense and avoid)

- ⇨ "full" structural qualification / certification process necessary
- ⇨ provide evidence to the mil. / civil authorities that the UAV can fly safely
- ⇨ comparable level of safety as for manned air systems

* German Aerospace Regulation

Summary of Influence Factors for UAV Lifecycle

Critical Elements for Vehicle Structure which need special attention for UAVs :

Element:	Influenced by:
Structural Design Criteria	⇨ Usage, Handling, Logistics, Safety
Material Selection criteria	⇨ Non-Recurring Cost, Production Volume
Design Methodology	⇨ Corrosion / Wear / Ageing control / Variability
Analysis and Test Reqm. /Procedure	⇨ Development time and cost
Validation and Verification Concept	⇨ Project Development cycle (Spirals)
Flight Envelope Expansion	⇨ Clearance Process, Development cycles
In-Service Usage Monitoring	⇨ Lifing and Maintainability Requirements

EADS - MAS UAV demonstrator programme

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